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Implement Replacement Coating for Cadmium Brush Plating on Department of Defense Weapon System

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Report Documentation Page

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Project Details

- **First Year of a Three Year Effort**
- **Numerous Agencies / Companies Involved (partial list)**
  – Air Force Research Laboratory
  – Air Force Depots
  – NAVSEA
  – Concurrent Technologies Corporation (CTC)
  – Boeing
  – Matco Associates
  – Harris Consulting

Problem Statement

- Cadmium (Cd) plating is used on steel mating surfaces for grounding and bonding on a DoD Weapon System
  - Federal regulations of Cd have increased to protect human health and the environment
  - Rate of phase-out and cost have also increased
- Maintenance, repair, and overhaul operations of a component of the same weapon system have recently been transitioned to a different DoD facility
  - New DoD facility had previously eliminated cadmium plating
  - DoD facility requested USAF for replacement coating in the weapon's component

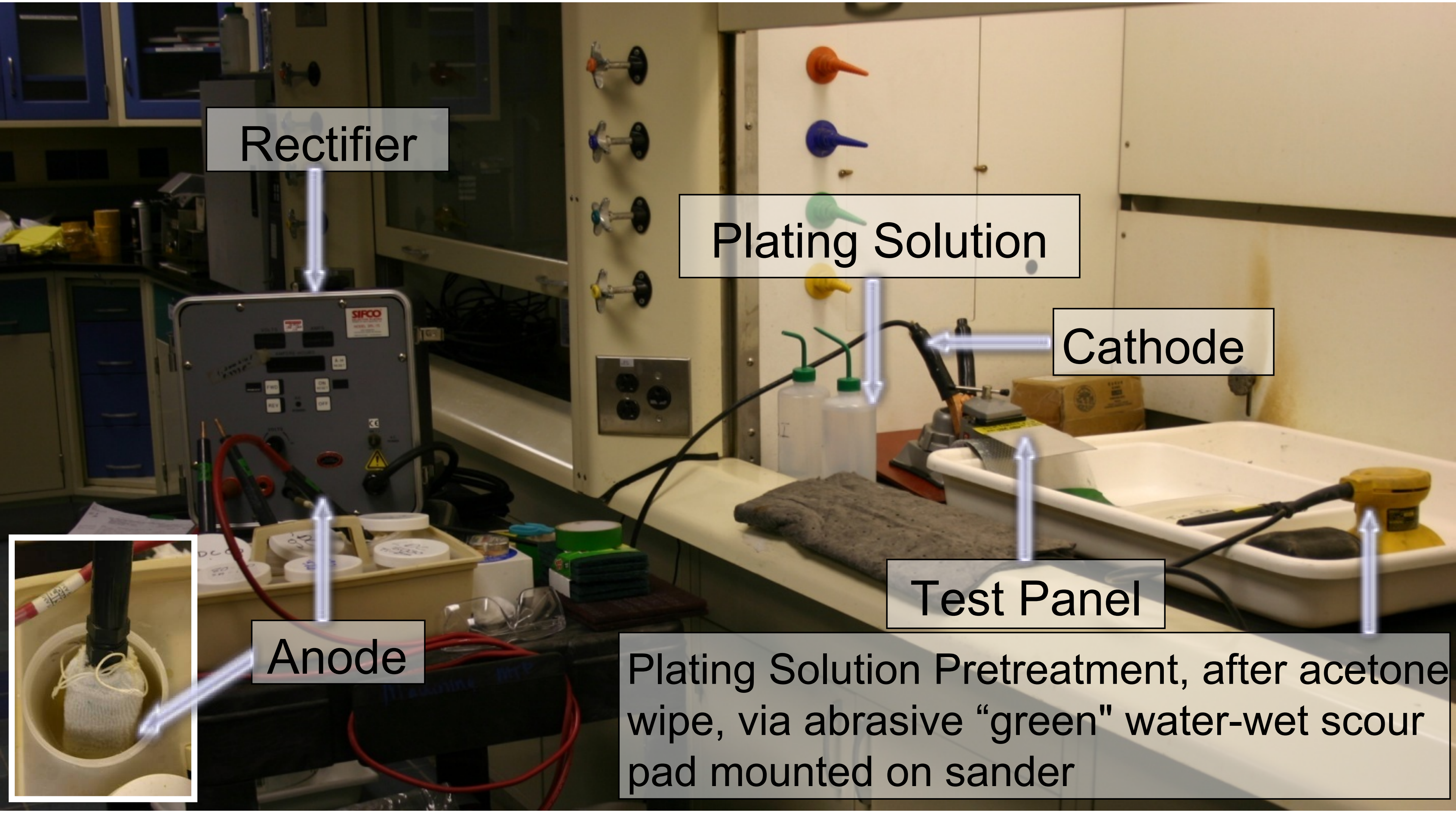
Conduct Electricity During Service

- Mating surfaces have dimensional tolerances
- Iron oxide is insulating and expands part volume
- Cd oxide is semi-conductive and non-voluminous

Objectives

- Identify replacement chemicals and required equipment for processing at DoD facility
- Investigate replacement repair plating process
- Define the process and testing criteria for alternatives
- Perform optimization testing on candidate coatings
- Recommend the process to be implemented after passing the demonstration / validation testing

Example Brush Plating Set-up



Dip anode in chemical; supplement from squirt bottle

Processing & Performance Replacement Requirements

- Meet SAE-AMS-QQ-P-416, Type I Class 2 Specification
  - no chromate conversion coating
  - 0.3 to 0.5 mils coating thickness
- Process the part coating within the repair production period
- Be compatible with DoD facility and worker capability
- Preserve the dimensional tolerance for the mating parts
- Sacrificially protect mild steel from corrosion
- Comparable or lower electrical resistivity than Cd during the service life
- Negligible change in volume between as-plated and end of service life (similar to Cd).

Eliminate Cd, Pb (and Ni?) Alts.

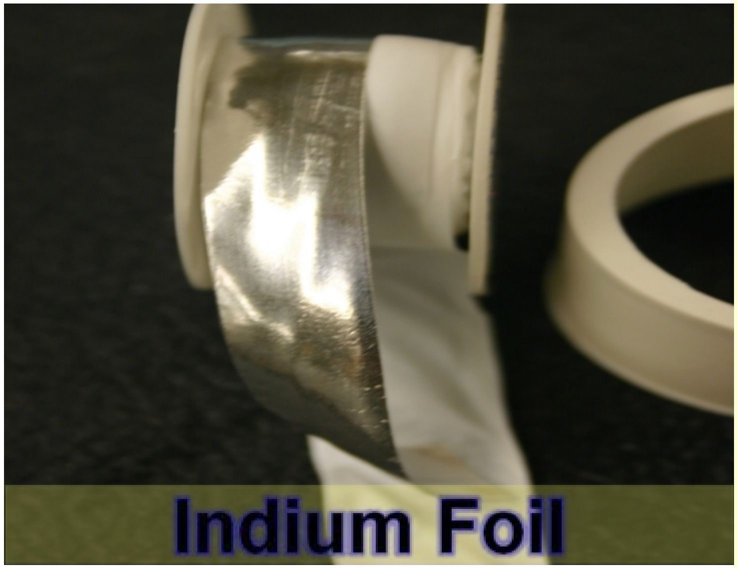
1. Aluminum
2. ~~Cadmium-titanium~~
3. Zinc
4. ~~Lead~~
5. ~~Zinc-cadmium~~
6. Nickel X?
7. Zinc-nickel X?
8. ~~Nickel-cadmium~~
9. Tin
10. ~~Tin-cadmium~~
11. Tin-nickel X?
12. Tin-zinc
13. Acrylic X?*
14. Epoxy X?*
15. Fluorocarbons X?*
16. Nylon X?*
17. Polyester X?*
18. Polyurethane X?*

* Organic coatings are unknown to be sacrificial sufficiently, when applied at 0.5 mils or less

Remaining Alts. per QQ-P-416

Alternative	Notes
~~1. Aluminum~~	Sacrifices to protect steel, converting to an alumina, which is an electrical insulator
~~2. Zinc~~	Also sacrificial to protect mild steel from corrosion; zinc oxide is 10X to 100X more electrically insulating than cadmium oxide
~~3. Tin~~	Plated tin is sacrificial to protect mild steel in seawater, but tin oxide is 10X more electrically insulating than cadmium oxide
4. Tin-zinc	Known to be sacrificial to protect mild steel, but its oxides' electrical resistivity is unknown and needs to be tested

Could Indium / Indium Alloy be an Alternative?



- ✓ Not considered hazardous
- ✓ Commercial brush plating products can plate indium within thickness tolerances
- ✓ Sacrificial to mild steel (in sea water) and its couple to mild steel produces a potential <0.15 volts
- ✓ Electrically conductive, similar to Cd
- – Metal "cold welds" to itself / <u>Alloy Avoids "cold weld" issue</u>
- – Metal subject to halide attack / Alloy unknown to halide attack

Indium in a Galvanic Series

Lower Number is More Anodic

Active (Anodic)

1. Magnesium
2. Manganese
3. Zinc (plated)
4. Aluminum
5. Cadmium (plated)
6. **Indium**
7. Tin (plated)
8. Steel 1010
9. Iron (cast)
10. Copper (plated)
11. Nickel (plated)
12. Cobalt
13. Bismuth
14. Tungsten
15. Titanium
16. Silver
17. Gold
18. Graphite

Noble (Less Anodic)

MIL-STD-889; Series for Seawater

Replacements Down-selection

Key Requirements	Candidate Cd Plating Replacement							
Processing	Al	Zn	Ni	Sn	Zn-Ni	Sn-Ni	Sn-Zn	Sn-In
Meet EHS Standards	P	P	?/F	P	?/F	?/F	P	P
Fits within Overhaul Schedule	?	P	P	P	P	P	P	P
Fits with Worker Capability	?	P	P	P	P	P	P	P
Performance								
Coating Thickness	P	P	P	P	P	P	P	P
Adhesion to substrate	P	P	P	P	P	P	P	P
Contact Impedance	F	F	F	F	?	?	?	?
Expansion of Corrosion Products	F	F	F	P	?	?	P	?
Sacrificial Corrosion Protection	P	P	F	P	?	?	P	P
Whisker Growth (FOR INFO)	?	F	P	F	P	P	?	?

Al = Aluminum; In = Indium; Ni = Nickel; Sn = Tin; Zn = Zinc.
“P” = Pass; “F” = Fail; “?” = Unknown; “?/F” = Questionable Future.

Select Commercial Chemistries

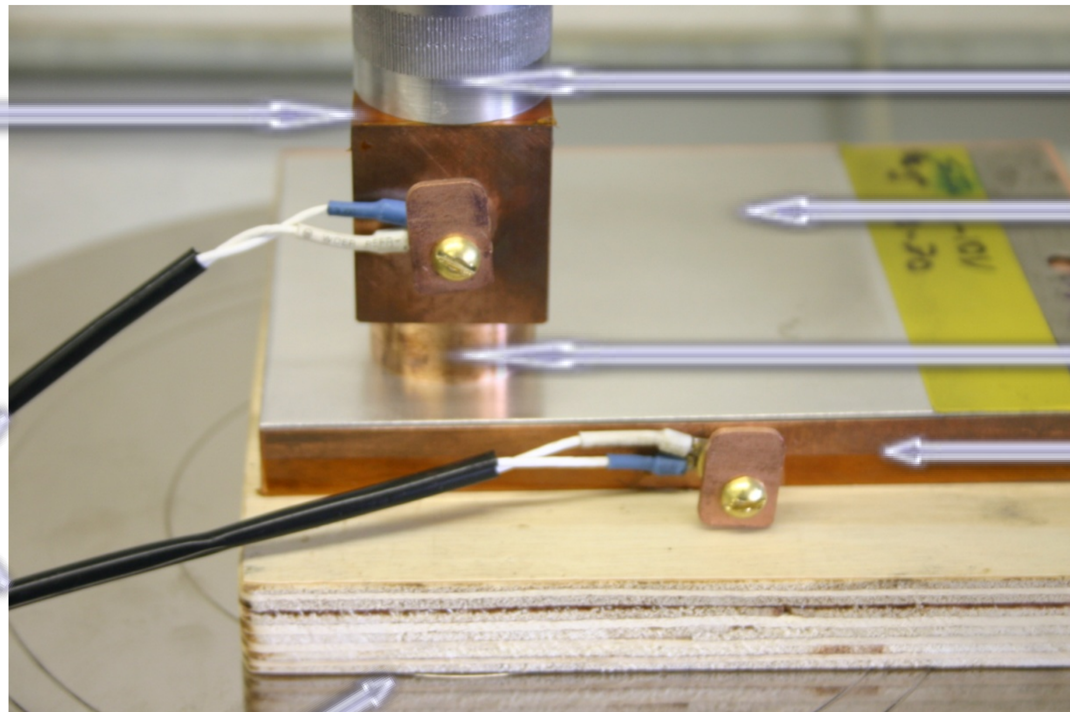
Alternatives	Notes
1. Tin-zinc	Known to be sacrificial to protect mild steel, (but its oxides' electrical resistivity is unknown and needs to be tested). Prior work encountered processing inconsistency for target metal alloy composition.
2. Tin-indium	Sacrificial to mild steel (in seawater) and electrically conductive, similar to Cd; avoids "cold weld" issue. Possibility of halide attack is unknown. Processing inconsistency similar to tin-zinc is a concern.
Contingency	**Notes**
3. Zinc-nickel	Known to be sacrificial to protect mild steel when its nickel content is <25-30% by weight; its oxides' electrical resistivity is a concern and needs to be tested. Possible worker health and safety concern.

Alts. Chosen for Round 1 Tests

Alternative Coating	Composition (nominal)
Cadmium	100% cadmium
Tin-zinc @ 7 volts(1)	90% tin, 10% zinc
Tin-zinc @ 12 volts (2)	70% tin, 30% zinc
Tin-indium (1)	80% tin, 20% indium
Tin-indium (2)	90% tin, 10% indium
Tin-indium (3)	50% tin, 50% indium
Tin-indium (4)	60% tin, 40% indium
Zinc-nickel (dip plated coating)	82% zinc, 18% nickel

Impedance Bonding

Electrical Isolation (Kapton® Tape)



Load (200-pounds/inch^2)

Panel

Upper Electrode (1-inch^2 Area)

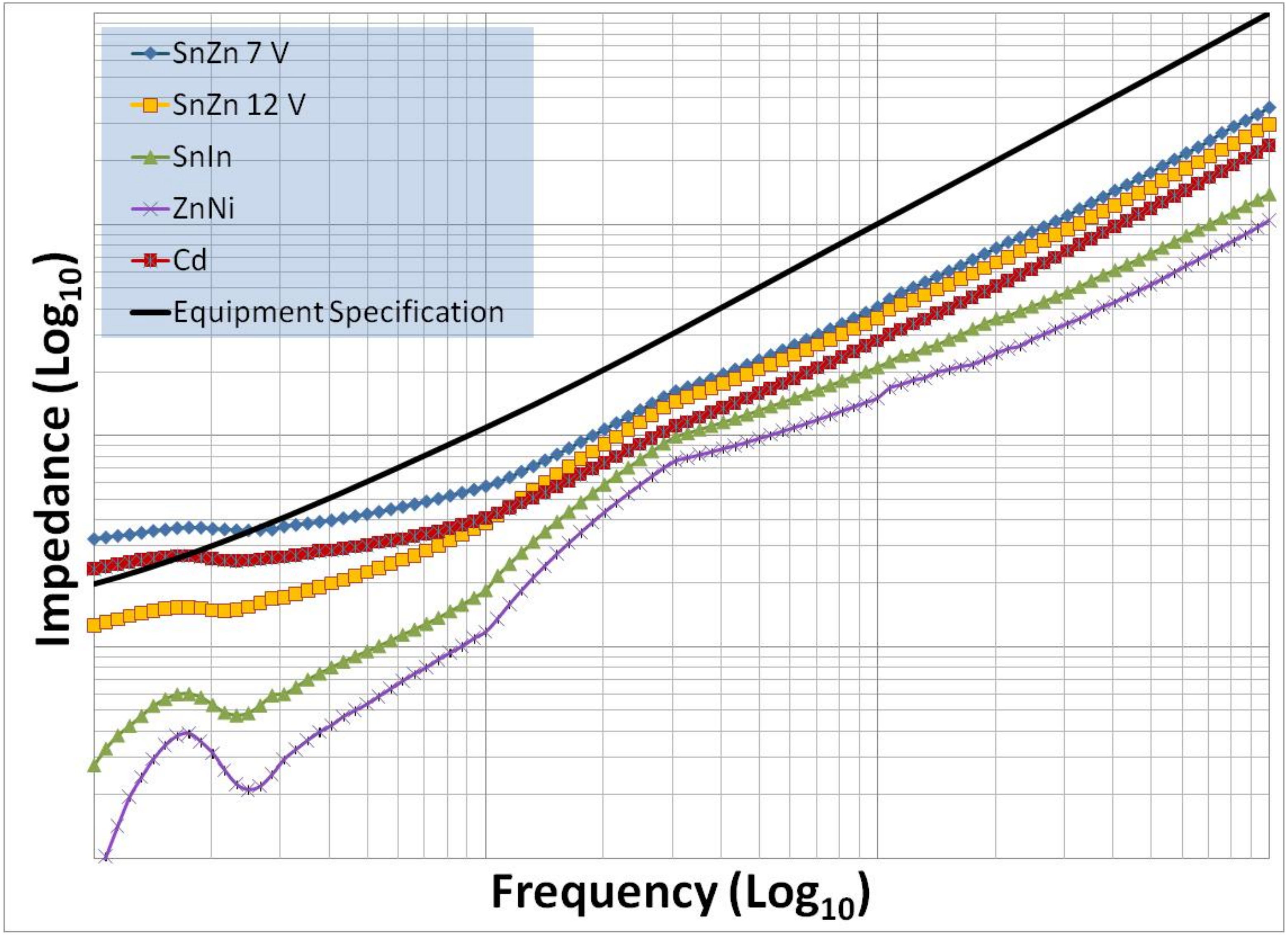
Lower Electrode (= Panel Area)

To 4-Wire Low Contact Resistance Meter

Electrical Isolation (plywood)

Test set-up follows MIL-DTL-81706

Impedance Results, Round 1

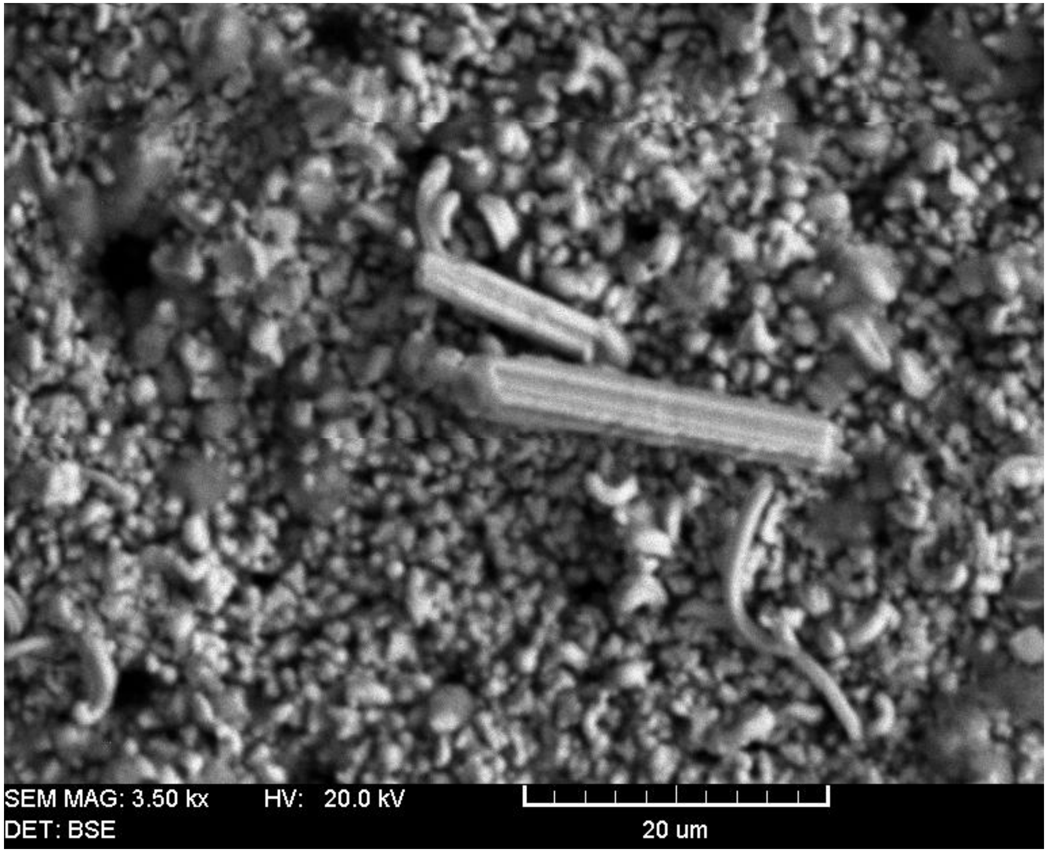


Whisker Growth

One panel of tin-zinc alloy plated panels (at 12-volts processing) produced whiskers within 1,000 hours of exposure at 131°F and 85% Relative Humidity.

All panels passed under ambient test conditions.

Test is being conducted for information.



Tin whiskers on tin-zinc alloy plating. All other tin-zinc, tin-indium and zinc-nickel alloy plated panels had passed within 1,000 hours of testing.

Status of Testing

Round 1	Status
Appearance	Complete
Coating Thickness	Complete
Adhesion	Complete
Composition	Complete
Impedance Bonding	Complete
Round 2	**Status**
Whisker Growth	Completed first of three 1,000 hour intervals

Test Results

Alternative Coating	Appearance	Thickness	Composition	Adhesion	Impedance As Plated	Whisker Growth, High Temp, Humidity	Whisker Growth, Ambient Temp, Humidity
Cadmium	X	X	X	P	P	NW	NW
30% tin, 70% zinc, 7 volts	X	X	X	P	P	NW	NW
30% tin, 70% zinc, 12 volts	X	X	X	P	P	W	NW
90% tin, 10% indium (COTS)	X	X	X	F	Not Tested		
90% tin, 10% indium (*CTC* prepared)	X	X	X	F	Not Tested		
50% tin, 50% indium	X	X	X	P	P	NW	NW
60% tin, 40% indium (~COTS)			X	P	Not Tested		
85% zinc, 15% nickel (COTS)	X	X	X	P	P	NW	NW

“COTS” = Commercial Off-The-Shelf”

Summary

- Mission Essential Need to replacement Cadmium coating on DoD weapon system with “greener” / safer alternative(s)
- Replacement needs to be sacrificial to mild steel, and electrically conductive throughout its service – this limits the options.
- Round 1 tests of commercial products are completed
- An additional commercial Zn-Ni product is being tested to replace the first Zn-Ni coating
  - First product was a dip plating process (not feasible in this application)
  - Brush plating process is needed
- Selecting three products for Round 2 testing:
  - Tin-indium
  - Tin-zinc
  - Zinc-nickel
- Round 2 testing is underway

Back Up Slides

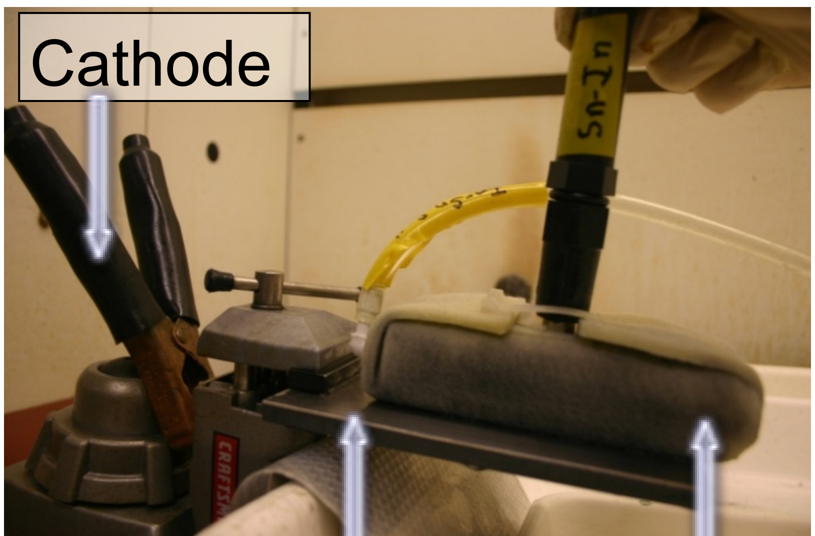
Background

- Cadmium has been a good coating for this weapon system.
  - Some of the mild steel component mating surfaces are electroplated with Cd
  - Prevent corrosion
    - Sacrificial to prevent formation of oxides of mild steel
    - Galvanic couple with aluminum alloys and stainless steel
  - Ensure a high electrical conductivity and sufficient grounding path during its service life
  - Provide the ability to withstand harsh weapon system environments
- Cd coating / repair process by brush plating that references SAE-AMS-QQ-P-416

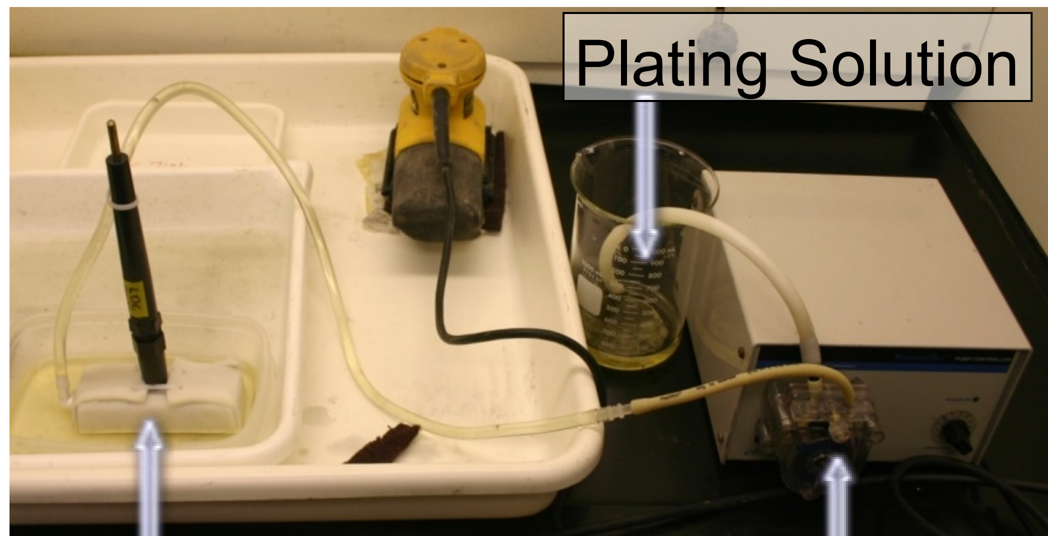
Alternate Anode Arrangement

Anode Machined for Metered Chemical
(either graphite [shown] or plastic for dimensionally stable)

Cathode



Plating Solution



Test Panel

Sleeved Anode

Chemical Metering Pump

Meter chemical to anode, through its sleeve, and onto the part

Cd Spot Repair (Brush) Plating

Procedure:

1. Remove soils/corrosion from plated surfaces
2. Activate the substrate and undamaged Cd
3. Brush plate Cd onto the activated areas:
   - Wrap sacrificial Cd anode in an absorbent sleeve
   - Keep the anode sleeve wet with plating solution
   - Apply a steady, uniform anode motion on the part
   - Use a constant voltage until the target ampere-hour is reached
4. Inspect the Cd plating quality

Alternatives (Alts.) per QQ-P-416

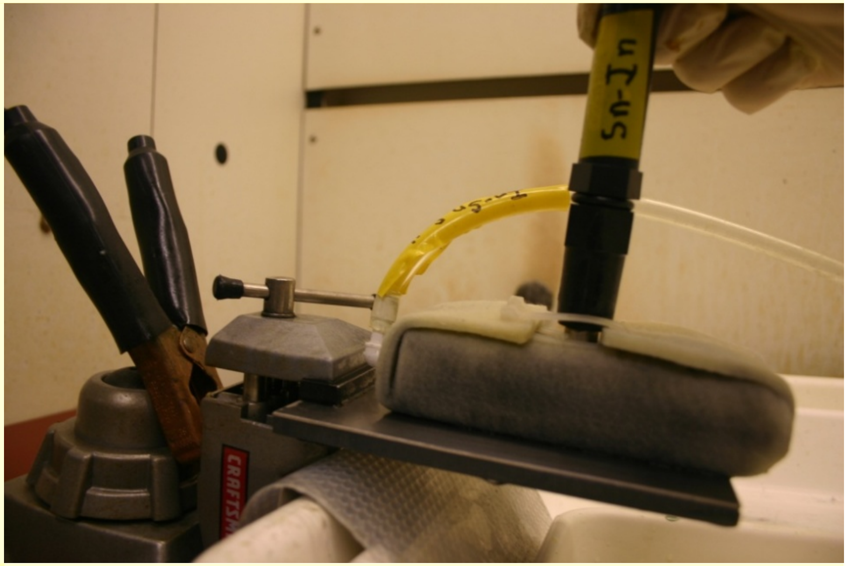
1. Aluminum
2. Cadmium-titanium
3. Zinc
4. Lead
5. Zinc-cadmium
6. Nickel
7. Zinc-nickel
8. Nickel-cadmium
9. Tin
10. Tin-cadmium
11. Tin-nickel
12. Tin-zinc
13. Acrylic
14. Epoxy
15. Fluorocarbons
16. Nylon
17. Polyester
18. Polyurethane

Caveats of Indium Alloys

1. Low temperature eutectic:
   - The tin-indium system eutectic is 244°F at ~48.3 weight % tin
   - The cadmium-indium-tin system eutectic is ~199°F
   - Good for a solder
2. Greater hardness than both Cd and indium:
   - Less deformable on the mating surfaces
   - Potentially reduces the contact between these surfaces and electrical conduction
3. Relatively expensive; therefore, conduct a review of its cost/benefit to adopt indium alloy plating

Indium Alloy Brush Plating

- Start at 6 volts, adjust for target current density
  - Nominal average of 2.5 amperes/square inch
- Manage the process resistive heat, which raises the temperature of the anode and a thin panel
  - Use a thicker, ⅛- to ¼-inch thick panel
  - Convert the anode to platinum wire instead of graphite
  - Feed the plating solution through the anode to cool it
- Use a soft anode sleeve material



Indium alloy plating